THREE-DIMENSIONAL WATER WAVE PATTERNS IN GRAVITY AND GRAVITY-CAPILLARY RANGE

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LONG-TERM GOAL

To develop a new approach to the description of sea surface taking into account the presence of the coherent and phase correlated 3-d wind wave patterns observed frequently in the gravity and gravity-capillary range. The eventual goal is to develop a ‘model of the surface’ adequate for remote sensing and helpful for the parametrization of the small-scale ocean-atmosphere momentum transfer.

SCIENTIFIC OBJECTIVES

The main objectives of the study are: to achieve understanding of the physical mechanisms responsible for the formation of 3-d wind wave patterns in the gravity and gravity-capillary range. To develop the experimental techniques of their registration, the methods of data analysis adequate for their selection in the field records and to create the adequate mathematical models. The objectives include investigation of the specifics of EM wave scattering due to the coherent 3-d wave patterns.

APPROACH

Two approaches have been taken; they are:

1. *Theoretical Approach:*

   The fundamental idea is that the wave patterns can be considered as composed of a small number of interacting modes in properly chosen phase space and their evolution can be described in terms of dynamical systems with a few degrees of freedom. The main accomplishments of the present theoretical study are concerned with the wind waves of gravity range. Both analytical and numerical considerations are based on the Zakharov’s formulation of weakly nonlinear theory of water waves. The main specific features of our approach lie in the accurate description of quartic nonlinearity (five-wave processes), full utilization of the Hamiltonian symmetries and in taking into account non-Hamiltonian effects due to generation and dissipation of waves. Non-conservative effects are considered as a perturbation to Hamiltonian dynamics.

   Another new theoretical approach focused on wave nonlinear interactions owing to the drift

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shear current was also developed. Its prime novel feature is that the coupled dynamics of wave field and shear current is considered.

2. *Experimental Approach*:
   Experimental study was carried out at Luminy large wind-wave facility by means of several experimental techniques:

   a) To get quantitative measurements a visualization technique allowing one to measure simultaneously the slopes of the waves in two perpendicular directions was implemented. The two-color visualization technique is a somewhat advanced modification of that used by Jahne & Riemer (1990). Capacitance wave gauge measurements were also carried out to ensure the accuracy of the optic measurements and to provide information on the motions of scales exceeding 1 m non-measurable by the optic system. For qualitative study of various regimes of 3-d pattern formation side-view photographs and S-VHS camera movies were also extensively used. The emergence of 3-d wave patterns was investigated both in the naturally generated wind wave field and for paddle generated waves (in the absence and the presence of wind).

   b) To study a particular mechanism of coherent pattern formation a series of experiments was carried out under specific conditions with the water surface covered by a thin plastic film. Use of the plastic film allowed us to study the phenomenon *per se*, as it filters out a number of physical factors of secondary importance in the present context.

The Key Individuals Participating in the Project are : (1) Dr. H. Branger, Dr. O. Kimmoun and Mr. F. Collard (all IRPHE-IOA) played the major role in making and testing of the installation for measuring short wind waves by means of the two-color visualization technique, the latter also participated in the experiments and data processing; (2) Dr. S. Annenkov (Shirshov Inst. of Oceanology) made the major contribution into creating the new simulation method for wind water waves. He was also involved into theoretical modeling and data processing; (3) Prof. A.Voronovich (ETL/NOAA, Boulder) plays central role in study of EM scattering from 3-d patterns; (4) Dr. S. Badulin (Shirshov Inst. of Oceanology) participated in theoretical modeling; and Dr. C. Kharif (IRPHE-IOA) participated in theoretical modeling and testing of the new simulation algorithm.

WORK COMPLETED

The following works have been completed:

1. The observations of 3-d patterns of paddle waves amplified by wind have been accomplished. A new type of horse-shoe patterns has been found. The bulk of the planned measurements of wind gravity-capillary waves was done. The necessary data are provided for the EM scattering study to begin and data analysis. A preliminary data analysis was carried out;

2. This year the new algorithm of wave field simulation developed in 1996 was extensively tested and used to study paddle wave evolution. Wind, dissipation and the presence of noise in the wave field were taken into account; and

3. Theoretical study of the wind wave horse-shoe patterns has been accomplished. A new model of sporadic horse-shoe patterns has been developed. The model explains the most often observed sporadic character of the patterns, the physical mechanisms of their selection and

the specific asymmetry of their fronts (see Figure 1).

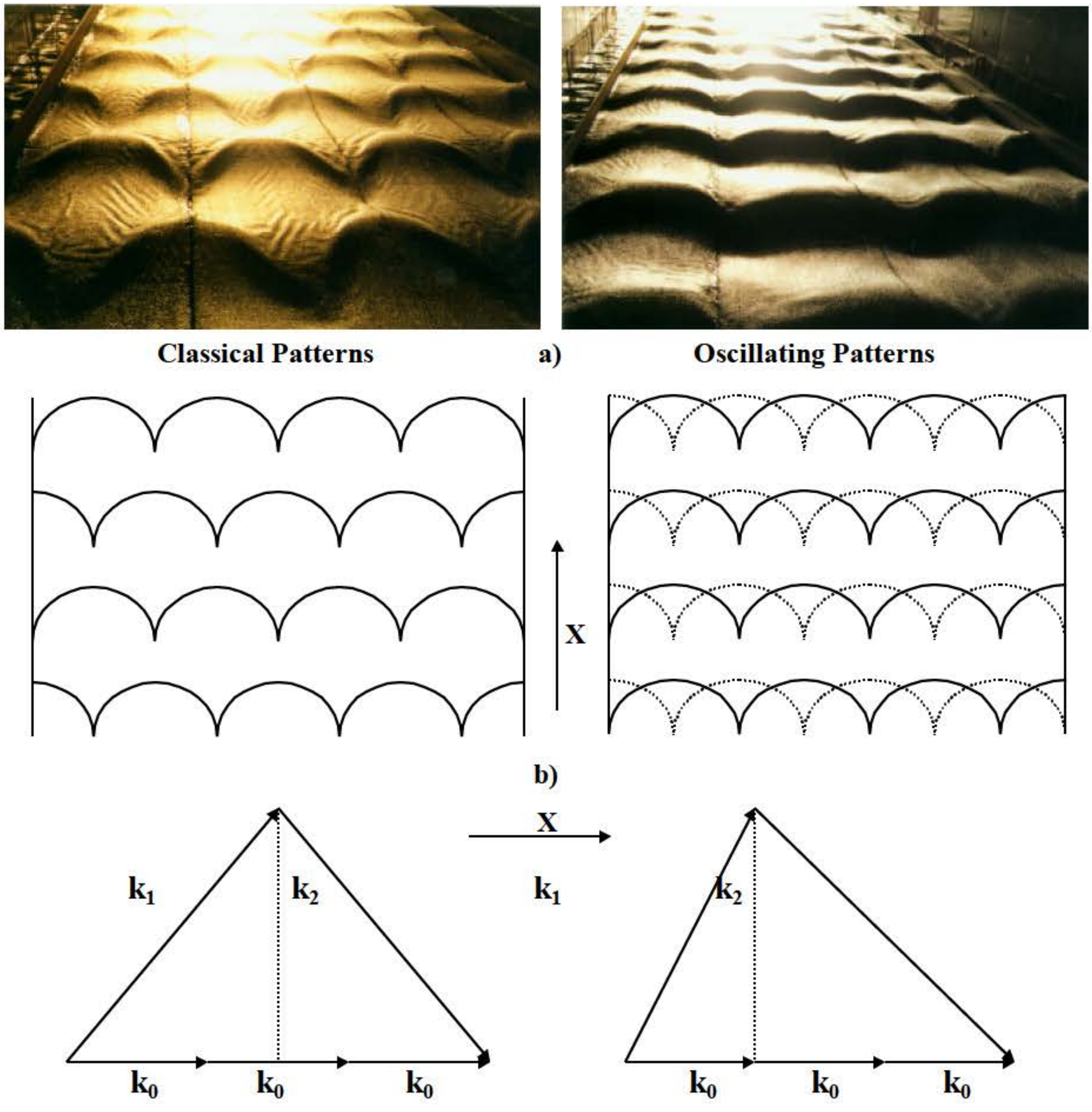

Figure 1. The "Classical" (left) and the "New" Oscillating (right) Horse-Shoes Patterns Observed in the Tank: a) backward view; b) schematic view of the patterns in the reference frame moving with the wave phase velocity: the classical patterns are steady while the new patterns oscillate between the solid line and the dashed line; c) the wavevectors quintets composing the classical symmetric patterns and the new asymmetric ones.

RESULTS

The following results include:

1. Earlier we found coherent 3-d wave patterns to be an indispensable feature of the early stages of wind wave field evolution. Although the detailed study of these studies is yet to be done, we have identified the main distinct types of wave patterns and related them to particular combinations of wave parameters;
2. A new type of crescent shape wave patterns has been revealed (see Figure1). In contrast to the “classic” horse-shoe patterns which are nearly steady, the new ones are rapidly oscillating and have quite different spatial plan structure. It was found that the new patterns emerge due to quintet resonant interactions. Their harmonic constituents have been identified;
3. A new theoretical model, explaining the main features of the experimentally observed horse-shoe patterns in the gravity range, was developed. The patterns appear as a result of interplay between quartic nonlinearity and generation/dissipation of the wave field. In particular, the model explains sporadic character of the patterns, their specific front shape and the mechanisms of the mode selection; and
4. Numerical simulation of paddle wave evolution subjected to wind, dissipation and interaction with a low-amplitude noise revealed nontrivial low-dimensional dynamical regimes of wave-field evolution. The simulation was based on the new algorithm of wave field simulation we developed in 1996.

IMPACT/APPLICATION

The a priori presumed necessity of new approaches to description of water surface based on taking into account the presence of 3-d coherent wave patterns, at least for early stages of wave field evolution, has been confirmed. Some elements of importance for modeling of the sea surface both for remote sensing applications and for the parametrization of the momentum transfer at the air-sea interface have been elaborated.

PUBLICATIONS

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